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Super-light and pearl-chain technology for support of ancient structures.

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ABSTRACT: The patented super-light technology is inspired by ancient Roman concrete structures with strong concrete placed, where the engineer would like the forces to be, and light concrete fills out the shape stabilizing the strong and protecting it.

Pearl-chain technology is invented in order to create optimal and often curved paths of strong concrete assembled from smaller segments by prestressing wires, so that expensive curved moulds and supports can be avoided.

Pearl-chains can provide a resistance to impact and earthquake of ancient structures.

High-strength concrete and prestressed carbon fibre reinforcement may be applied, because the new technology solves the main problems for that, since the light aggregate concrete provides a fire protection needed for both materials and provides a stabilization of the slender cores in compression.

The paper explains more about the new technology and the structures it can be applied for.

Keywords: Roman concrete, super-light concrete, resistance, reinforcement, prestress

1 ANCIENT CONCRETE STRUCTURES



Figure 1. Phoenician glassware at British Museum. Photo K. Hertz.

1.1 The oldest concrete

The oldest concrete known by the authors is made by the Phoenicians, who had a huge glass industry (Hallager, 1997) based on the rich occurrence of fuel from cedar-wood in their home land (Fig.1). They

pulverized the glass and mixed it with limestone and water to create a calcium-silicate-hydrate that we call cement. Later they learned to dig fly ash at Santorini and use that instead of the pulverized glass, and next to the Phoenician queries at the island you find Roman queries.



Figure 2. Campi Flegrei. Photo K. Hertz.

The Romans also applied fly ash from other sources not at least the super volcano Campi Flegrei (Fig. 2) at Pozzuoli and they developed the concrete

structures using permanent moulds of brick at the surface of walls (Fig. 3) and pumice as a light aggregate for vaults and cupolas (Vitruvius, 1914, Lamprecht, 1985).

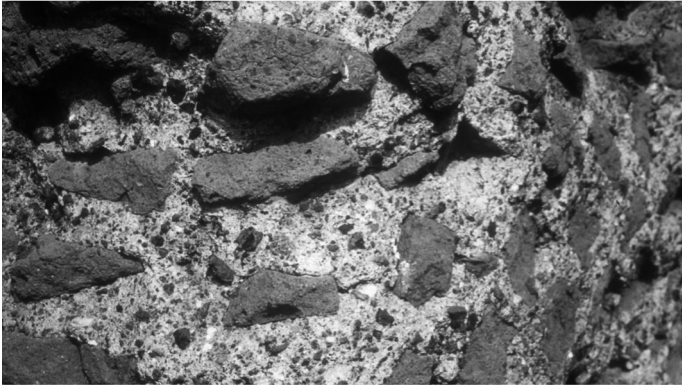


Figure 3. Close up of a Roman Wall. Photo K. Hertz.

1.2 Roman structures

The technology was developed to a high degree of perfection not at least by the architect Apollodorus of Damascus, who served Trajan and Hadrian.



Figure 4. Panteon. Photo K. Hertz.

In his cupolas like the Panteon (Fig.4) the light aggregate became increasingly lighter near the top (De Fine Licht, 1968), where also pots of clay could be applied to reduce the density of the material. At the same time the thickness of the shells also became smaller near the top. At the top a circular brick structure (Fig. 6) was often inserted as a horizontal compression ring giving a possibility of inserting an opening.

Furthermore, cupolas and vaults may be provided with crossing ribs (Fig. 5) increasing the ratio between stiffness and weight.



Figure 5. Panteon. Photo K. Hertz

All these measures made it possible to create larger spans and to improve the overall stability of the structure and ensure a better resistance to earthquake.



Figure 6. Villa Adriana. Photo K. Hertz.

The massive structures take the forces by compression in arches, vaults and wall plates, and slender brick plates may be placed across the sections of walls providing them with an improved cohesion and allowing sliding movements adopting energy from earthquakes (Harris, 1997).

Only one example of Roman iron reinforcement is known to the author improving the bending capacity of thin concrete slabs covering a duct for a hypocaust system in a villa in Klagenfurt (Huberti, 1964).



Figure 7. Villa Adriana. Photo K. Hertz.

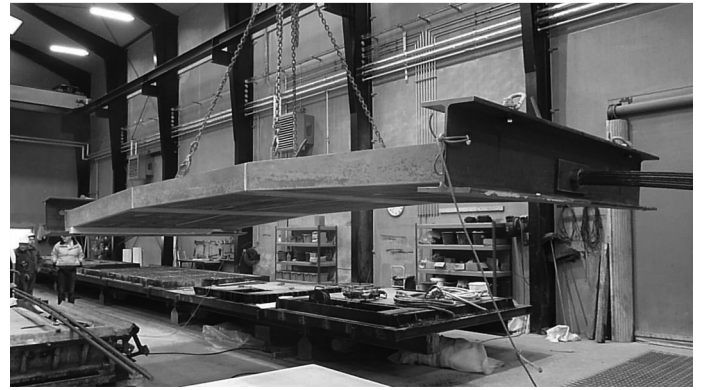


Figure 7. Pearl-chain vault. Photo K. Hertz.

2 MODERN STRUCTURES

2.1 Super-light structures.

The Roman application of light aggregate concrete for load-bearing structures, and application of different concrete materials in the same structure, has been a powerful inspiration developing the new super-light technology. Also the skilful application of minimal shapes (Fig. 7) and well thought solutions for details are worth studying for a present day engineer.

You may say that the author, by inventing the new technology, has taken a step back in time, and tried to imagine how a Roman engineer would construct, if he knew about modern engineering practice.

In super-light structures, compression zones of optimal shapes of a strong material like concrete or high-strength concrete are established and embedded in a light-aggregate concrete (Hertz, 2007, 2009-1).

The light concrete fills out the shape of the structure, applies the load to the compression zones, and stabilizes them, so that the strong concrete can be utilized better (Hertz and Bagger, 2010). Moreover, the light concrete protects the strong against physical impact and fire, which can damage the materials (Hertz 2005), and especially for high-strength concrete give rise to explosive spalling (Hertz 1984, 2003-1).

This changes the conception of a concrete structure from an artificial stone to a skeleton with soft parts.

2.2 Pearl-chain structures.

A pearl-chain reinforcement is a curved chain of segments of concrete assembled by one or more prestressing wires and acting with a concrete of less strength adjacent to it or surrounding it. The chain constitutes a curved compression zone like a spine of a skeleton.

The technologies of Super-light and pearl-chain structures are invented and patented at the Technical University of Denmark and placed in the start-up company Abeo Ltd.

By means of pearl-chain reinforcement, it becomes affordable to provide structures with shapes that have previously been unthinkable, and when self supported pearl-chains carry ultra-light moulds for example made of textile for the light concrete, scaffolding can often be completely avoided.

High-strength concrete with a compressive strength of 100-500 MPa is invented by Bache (Bache, 1981). It has severe problems with steam explosion in fire, which was soon discovered by the author (Hertz, 2003-1+2). Practically all explosive spalling occurs near the critical point for water-based steam 374°C.

So, protecting it by light concrete in a super-light structure solves the problem, and we can therefore now benefit from making very light supporting structures.

The same goes for carbon-fibre reinforcement that also can be protected by applying it for slack or prestressed reinforcement in super-light pearl-chain structures.



Figure 8. Library in Ephesus. Photo K. Hertz

In Figure 7 is shown a vault made from 3 flat super-light SL-deck elements assembled by prestressing. The concrete slab elements are provided with a duct and after casting mortar is cast in the joint grooves, and prestressing wires are tensioned in the duct.



Figure 9. Arch structure in Ephesus. Photo K. Hertz

This techniques of super-light and pearl-chain structures are obvious to apply for strengthening not only antique vaults and cupolas, but many fragile ruins as those on Fig. 8 and 9 providing them with an increased resistance against lateral impact such as the effect of earthquake.

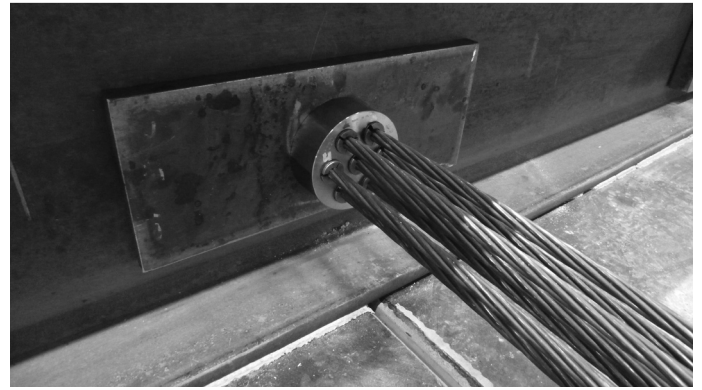


Figure 10. Anchorage of prestressing wires of a pearl-chain structure. Photo K. Hertz

The structures can be provided with light-aggregate concrete in which stabilizing compression zones of strong concrete are placed. Slack- or prestressed reinforcing wires, rods, or straps can be provided directly on the antique structures covered by the light concrete or embedded in ducts for post-tensioning, or holes may be established in disassembled parts opening possibilities for assembling into stable structures.

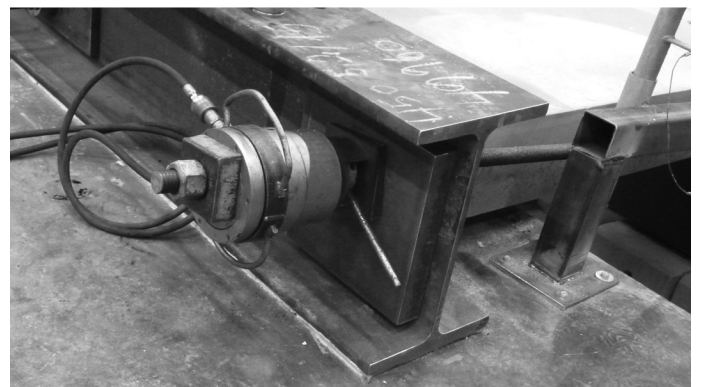


Figure 11. Tensioning a prestressing rod of a pearl-chain structure. Photo K. Hertz

Wires (Fig. 10) or rods (Fig. 11) of steel are traditionally used for prestressed structures, but rods or flat straps of carbon fibre reinforcement seem also to be advantageous to apply for pearl-chain reinforcing.

They are not susceptible to rust and the cover thicknesses needed can be minimized to consist of the light aggregate concrete parts of the final structure. (Schmidt, 2010).

CONCLUSIONS

Super-light and pearl-chain structures are invented at the Technical University of Denmark inspired by ancient Roman concrete building technology.

Since the same materials are applied as found in Roman concrete structures, the new technologies can provide ancient structures with stabilizing arches for support, tension ties to give coherence, and protecting and filling layers when they are strengthened or reestablished.

This may assist ancient structures, when they are strengthened or assembled from fragments, and in addition, an increased stability can be ensured for impact of earthquake and mechanical action, while stresses and interfaces between the materials involved can be obtained, which harmonize with those found in the original structures.

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